UNIT # 5
GRAVITATION

Q1. Who gave the idea of gravity?

Ans: The first man who came up with the idea of gravity was Isaac Newton. It was an evening of 1665 when he was trying to solve the mystery why planets revolve around the Sun. Suddenly an apple fell from the tree under which he was sitting. The idea of gravity flashed in his mind. He discovered not only the cause of falling apple but also the cause that makes the planets to revolve around the Sun and the moon around the Earth. This unit deals with the concepts related to gravitation.

Q2. What is meant by the force of gravitation?

Ans: The force of gravitation:

There exists a force due to which everybody of the universe attracts every other body. This force is called the force of gravitation.

Q3. Explain Newton's law of gravitation?

Ans: See Q # 5.9 from Exercise.

Q4. Explain that the gravitational forces are consistent with Newton's third law of motion?

Ans: Law of gravitation and Newton's third law of motion:

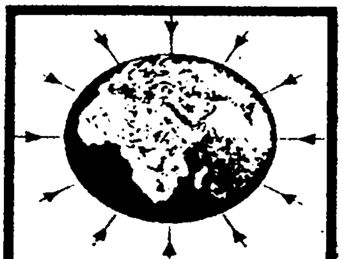
It is to be noted that mass m_1 attracts m_2 towards it with a force F while mass m_2 attracts m_1 towards it with a force of the same magnitude F but in opposite direction. If the force acting on m_1 is considered as action then the force acting on m_2 will be the reaction. The action and reaction due to force of gravitation are equal in magnitude but opposite in direction. This is in consistence with Newton's third law of motion which states, to every action there is always an equal but opposite reaction.

Q5. Explain gravitational field as an example of field of force?

Ans: Gravitational field:

The field in a region in space in which a particle would experience a gravitational force is called gravitational field.

It is assumed that a gravitational field exists all around the Earth due to the gravitational force of attraction of the Earth.



Gravitational field around the Earth is towards its centre

The weight of a body is due to the gravitational force with which the Earth attracts a body. Gravitational force is a non-contact force.

For example, the velocity of a body, thrown up, goes on decreasing while on return its velocity goes on increasing. This is due to the gravitational pull of the Earth acting on the body whether the body is in contact with the Earth or not. Such a force is called the **field force**. It is assumed that a **gravitational field** exists all around the Earth. This field is directed towards the centre of the Earth as shown by arrows.

Q6. Explain, what is meant by gravitational field strength?

Ans: Gravitational field strength:

In the gravitational field of the Earth, the gravitational force per unit mass is called the gravitational field strength of the Earth. It is 10 $N\,kg^{-1}$ near the surface of the Earth.

The gravitational field becomes weaker and weaker as we go farther and farther away from the Earth. At any place its value is equal to the value of g at that point.

Q7. How the mass of Earth can be determined?

Ans: See Q # 5.10 from Exercise.

Q8. Why does the value of *g* vary from place to place? Explain how the value of g varies with altitude.

Ans: See Q # 5.13 from Exercise.

Q9. Explain the variation of 'g' with altitude.

OR

What is the effect of the following on the gravitational acceleration?

a. Mass of a freely falling body.

b. Distance of freely falling body from the centre of the Earth.

c. Is there any difference between the values of g at the equator and at the poles? Explain.

Ans: (a) Since $g = G\frac{M_e}{R^2}$ ....(i)

Equation (i) shows that the value of g does not depend upon mass of the body. This means that light and heavy bodies should fall toward the centre of earth with the same acceleration.

b) The value of g varies inversely as the square of the distance i.e. $g \propto \frac{1}{R^2}$ if the distance from the centre of the earth is increased then the value of g will decrease. That is why the value of g at hills (Murree) is less than its value on the sea shore (Karachi).

c) Earth is not a perfect sphere. It is flattened at the poles for this reason the value of g at the pole is more than at the equator. Because polar radius is less than equatorial radius. ($g \propto \frac{1}{R^2}$)

Mini Exercise

1. Does an apple attract the Earth towards it?

Ans: Yes, according to the law of gravitation an apple attract the Earth towards it but its attraction is very small and cannot be felt.

2. With what force an apple weighing 1N attracts the Earth?

Ans: The force of attraction is equal to the weight of the object. So an apple weighing 1N attracts the Earth with 1N force.

3. Does the weight of an apple increase, decrease or remain when taken to the top of a mountain?

Ans: The value of g varies inversely as the square of the distance i.e. $g \propto \frac{1}{R^2}$.

Therefore the weight of an apple, decrease when taken to the top of a mountain due to less gravity of Earth.

DO YOU KNOW?

Value of g on the surface of a celestial object depends on its mass and its radius. The value of g on some of the objects is given below:

Object	g (ms^{-2})
Sun	274.2
Mercury	3.7
Venus	8.87
Moon	1.62
Mars	3.73
Jupiter	25.94

Q10. What are artificial satellites?

Ans: See Q # 5.14 from Exercise.

Q11. What are geostationary satellites also write their uses.

Ans: Geostationary satellites whose velocity relative to Earth is zero. These satellites remain stationary with respect to the Earth at a height of about 42300 km from the surface of Earth. These are used for global TV transmissions and for other telecommunication purposes.

As Earth also completes its one rotation about its axis in 24 hours, hence, these communication satellites appear to be stationary with respect to Earth. It is due to this reason that the orbit of such a satellite is called geostationary orbit.

Dish antennas sending and receiving the signals from them have fixed direction depending upon their location on the Earth.

Uses of geostationary satellites:

Such satellites are useful for the following purposes.

(i) Worldwide communication **(ii)** Weather observations
(iii) Navigation **(iv)** Other military uses

Note: Three geostationary satellites can cover the whole earth.

DO YOU KNOW?

Geostationary satellite:

The height of a geostationary satellite is about 42,300 km from the surface of the Earth. Its velocity with respect to Earth is zero.

DO YOU KNOW?

Global Positioning System (GPS):

Global Positioning System (GPS) is a satellites navigation system. It helps us to find the exact position of an object anywhere on the land, on the sea or in the air. GPS consists of 24 Earth satellites. These satellites revolve around the Earth twice a day with a speed of 3.87 kms^{-1}.

Q12. How Newton's law of gravitation helps in understanding the motion of satellites? On what factors the orbital speed of a satellite depends? OR
Derive the formula for the orbital speed of an artificial satellite?

Ans: See Q # 5.15 from Exercise.

DO YOU KNOW?

Moon is nearly 3,80,000 km away from the Earth. It completes its one revolution around the Earth in 27.3 days.

SUMMARY

1. **Newton's law of universal gravitation:** Newton's law of universal gravitation states that everybody in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.
2. The Earth attracts a body with a force equal to its weight.
3. **Gravitational force of attraction of the Earth:** It is assumed that a gravitational field exists all around the Earth due to the gravitational force of attraction of the Earth.
4. **Gravitational field strength of the Earth:** In the gravitational field of the Earth, the gravitational force per unit mass is called the gravitational field strength of the Earth. It is 10 N kg^{-1} near the surface of the Earth.
5. *Acceleration* $g = G\frac{M_e}{R^2}$
6. Mass of Earth $M_e = \frac{R^2 g}{G}$
7. g at an altitude h = $G\frac{M}{(R+h)^2}$
8. **Satellite:** An object that revolves around a planet is called a satellite.
9. The moon revolves around the Earth so moon is a natural satellite of the Earth.
10. **Artificial satellites:** Scientists have sent many objects into space. Some of these objects revolve around the Earth. These are called artificial satellites.
11. Orbital velocity $v_o = \sqrt{g_h(R + h)}$

QUESTIONS

5.1 Encircle the correct answer from the given choices:

i. Earth's gravitational force of attraction vanishes at

A. 6400 km B. infinity
C. 42300 km D. 1000 km

ii. Value of *g* increases with the

A. increase in mass of the body B. increase in altitude
C. decrease in altitude D. none of the above

iii. The value of *g* at a height one Earth's radius above the surface of the Earth is:

A. $2g$ B. $\frac{1}{2}g$

C. $\frac{1}{3}g$ D. $\frac{1}{4}g$

iv. **The value of g on moon's surface is 1.6 ms^{-2}. What will be the weight of a 100 kg body on the surface of the moon?**

A. 100 N B. 160 N

C. 1000 N D. 1600 N

v. **The altitude of geostationary orbits in which communication satellites are launched above the surface of the Earth is:**

A. 850 km B. 1000 km

C. 6400 km D. 42,300 km

vi. **The orbital speed of a low orbit satellite is:**

A. zero B. 8 ms^{-1}

C. 800 ms^{-1} D. 8000 ms^{-1}

Answers

i. B	ii. C	iii. D	iv. B	v. D	vi. D

5.2 What is meant by the force of gravitation?

Ans: The force of gravitation:

There exists a force due to which everybody of the universe attracts every other body. This force is called the force of gravitation.

5.3 Do you attract the Earth or the Earth attracts you? Which one is attracting with a larger force? You or the Earth.

Ans: The answer of the question can be found two ways. First, we can use Newton's Third Law. If object "A" exerts a force on object "B", then object "B" will exert an equal force back on "A". This makes it pretty clear the forces are equal.

Second, we can use Newton's Law of Gravitational force. "The force that one mass exerts on a second mass is proportional to the product of the two masses". This means if we calculate the force the Earth exerts on us, we multiply the Earth's mass times our mass. And if we calculate the force we exert on the Earth ,we again multiply the two masses. Another words we do the exact same calculation, so we will get the same answer.

5.4 What is a field force?

Ans: Field force:

The gravitational pull of the Earth acting on the body whether the body is incontact with the Earth or not is called field force.

5.5 Why earlier scientists could not guess about the gravitational force?

Ans: Earlier scientists could not guess the force of gravitation between two masses, because it is of very small value. It could be detected only by very sensitive instrument which were not invented at that time.

5.6 How can you say that gravitational force is a field force?

Ans: It is true that the force of gravity can be described as a force field Any object having mass will create a gravitational attraction in all directions, with decreasing intensity as the distance from the object increases.

The weight of a body is due to the gravitational force with which the Earth attracts a body. Gravitational force is a non-contact force.

For example, the velocity of a body, thrown up, goes on decreasing while on return its velocity goes on increasing. This is due to the gravitational pull of the Earth acting on the body whether the body is in contact with the Earth or not. Such a force is called the **field force**. It is assumed that a **gravitational field** exists all around the Earth.

5.7 Explain, what is meant by gravitational field strength?

Ans: Gravitational field strength:

In the gravitational field of the Earth, the gravitational force per unit mass is called the gravitational field strength of the Earth. It is $10\ N\ kg^{-1}$ near the surface of the Earth.

The gravitational field becomes weaker and weaker as we go farther and farther away from the Earth. At any place its value is equal to the value of g at that point.

5.8 Why law of gravitation is important to us?

Ans: Importance of law of gravitation:

As universal law of gravitation is important in releasing satellites from the earth in the orbits and it also gives the reason that why earth revolves around the sun.

The universal law of gravitation describes the phenomenon like the gravitational force between a planet and a star, rotation and revolution of heavenly bodies and galaxies.

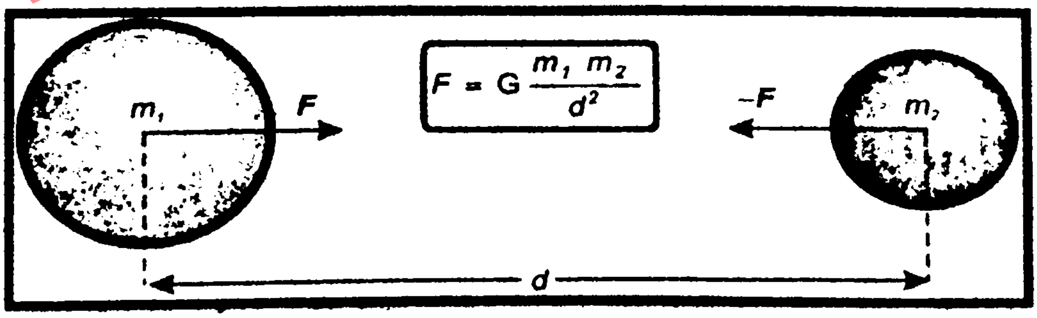
5.9 Explain the law of gravitation.

Ans: Law of gravitation:

Everybody in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

Explanation:

Consider two bodies of masses m_1 and m_2. The distance between the centres of masses is d.



According to the law of gravitation, the gravitational force of attraction F with which the two masses m_1 and m_2 separated by a distance d attract each other is given by:

$$F \propto m_1 m_2 \quad \text{...........(i)}$$

$$F \propto \frac{1}{d^2} \quad \text{...........(ii)}$$

By combining (i) and (ii) we get

$$\text{or} \qquad F \propto \frac{m_1 m_2}{d^2}$$

$$F = G\frac{m_1 m_2}{d^2} \quad \text{...........(iii)}$$

Universal constant of gravitation (G):

Here G is the proportionality constant. It is called the universal constant of gravitation. Its value is same everywhere.

In SI units the value of G is $6.673 \times 10^{-11}\ Nm^2\ kg^{-2}$.

5.10 How the mass of Earth can be determined?

Ans: Mass of the earth:

Consider a body of mass m on the surface of the Earth. Let the mass of the Earth be M_e and radius of the Earth be R.

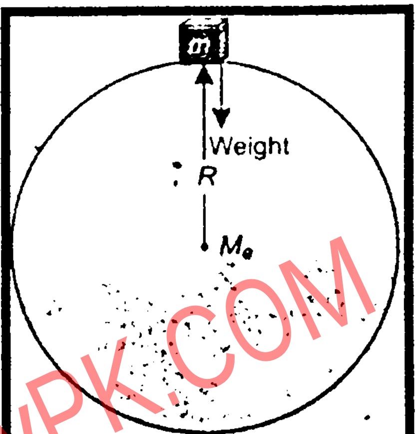


Figure: Weight of a body is equal to the gravitational force between the body and the Earth.

According to the law of gravitation, the gravitational force F of the Earth acting on a body is given by

$$F = G\frac{mM_e}{R^2} \quad \text{.............. (i)}$$

But the force with which Earth attracts a body towards its centre is equal to its weight W. Therefore,

$$F = W = mg$$

$$\text{or} \quad mg = G\frac{mM_e}{R^2}$$

$$g = G\frac{M_e}{R^2}$$

$$\text{and} \quad M_e = \frac{R^2 g}{G} \quad \text{.............. (ii)}$$

Mass M_e of the Earth can be determined on putting the values in equation (ii).

$$M_e = \frac{(6.4 \times 10^6\ m)^2 \times 10\ ms^{-2}}{6.673 \times 10^{-11}\ Nm^2kg^{-2}} = 6.0 \times 10^{24}\ kg$$

Thus, mass of the Earth is 6.0×10^{24} kg.

5.11 Can you determine the mass of our moon? If yes, then what you need to know?

Ans: Yes, we can find the mass of moon by using the law of gravitation.

$$M_m = \frac{R^2 g_m}{G}$$

Where M_m = mass of moon

R = radius of moon

g_m = gravitational acceleration on moon

G = gravitational constant = $6.673 \times 10^{-11}\ Nm^2kg^{-2}$

5.12 Why does the value of *g* vary from place to place?

Ans: Variation of g with altitude:

The value of g is inversely proportional to the square of the radius of the Earth ($g \propto \frac{1}{R^2}$).

But it does not remain constant. It decreases with altitude. Altitude is the height of an object or place above sea level. The value of g is greater at sea level than at the hills.

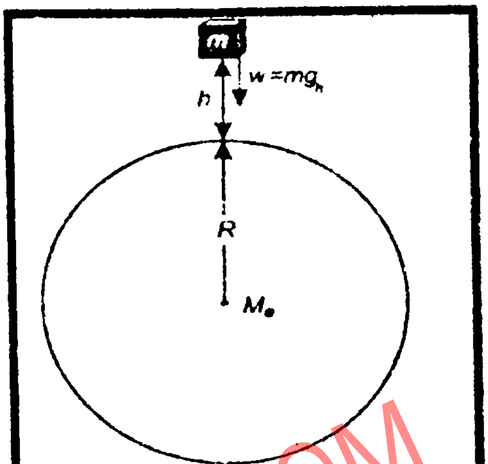
5.13 Explain how the value of g varies with altitude.

Ans: Variation of g with altitude:

Equation $g = G\frac{M_e}{R^2}$ shows that, the value of acceleration due to gravity g depends on the radius of the Earth at its surface.

The value of g is inversely proportional to the square of the radius of the Earth ($g \propto \frac{1}{R^2}$).

But it does not remain constant. It decreases with **altitude**. Altitude is the height of an object or place above sea level. The value of g is greater at sea level than at the hills.



Weight of a body decreases as its height increases from the surface of the Earth

Explanation:

Consider a body of mass m at an altitude h. The distance of the body from the centre of the Earth becomes $R + h$.

Therefore, using equation ($g = G\frac{M_e}{R^2}$), we get

$$g_h = G\frac{M_e}{(R+h)^2} \quad \ldots\ldots\ldots\ldots (i)$$

Note:

According to the above equation, we come to know that at a height equal to one Earth radius above the surface of the Earth, g becomes one fourth ($\frac{1}{4}$) of its value on the Earth.

Similarly at a distance of two Earths radius above the Earth's surface, the value of g becomes one ninth ($\frac{1}{9}$) of its value on the Earth.

5.14 What are artificial satellites?

Ans: Satellites:

An object that revolves around a planet is called a satellite. The moon revolves around the Earth so moon is a natural satellite of the Earth.

Artificial satellites:

Scientists have sent many objects into space. Some of these objects revolve around the Earth. These are called artificial satellites.

Uses of Artificial satellites:

Most of the artificial satellites, orbiting around the Earth are used for communication purposes. Artificial satellites carry instruments or passengers to perform experiments in space.

A satellite is orbiting around the Earth at a height h above the surface of the Earth.

Communication satellites take 24 hours to complete their one revolution around the Earth.

5.15 How Newton's law of gravitation helps in understanding the motion of satellites?

Ans: Motion of artificial satellites:

A satellite requires centripetal force that keeps it to move around the Earth. The gravitational force of attraction between the satellite and the Earth provides the necessary centripetal force.

Consider a satellite of mass m revolving round the Earth at an altitude *h* in an orbit of radius r_0 with orbital velocity v_0. The necessary centripetal force required is given by equation.

$$F_c = \frac{mv_o^2}{r_o} \quad \ldots\ldots\ldots\ldots \text{(i)}$$

This force is provided by the gravitational force of attraction between the Earth and the satellite and is equal to the weight of the satellite w′ (mg_h). Thus

$$F_c = w' = mg_h \quad \ldots\ldots\ldots \text{(ii)}$$

From (i) and (ii) we get

or $$mg_h = \frac{mv_o^2}{r_o}$$

or $$v_o^2 = g_h\, r_o$$

or $$v_o = \sqrt{g_h\, r_o} \quad \text{(iii)}$$

as $$r_o = R + h$$

$$v_o = \sqrt{g_h\,(R+h)} \quad \text{(iv)}$$

Equation (iii) gives the velocity, which a satellite must possess when launched in an orbit of radius $r_o = (R + h)$ around the Earth.

An approximation can be made for a satellite revolving close to the Earth such that $R >> h$.

$$R + h \approx R$$

and $$g_h \approx g$$

$$v_o = \sqrt{g\,R} \quad \ldots\ldots\ldots\ldots \text{(v)}$$

A satellite revolving around very close to the Earth, has speed v_o nearly $8\ kms^{-1}$ or $29000\ kmh^{-1}$.

5.16 On what factors the orbital speed of a satellite depends?

Ans: Since orbital speed = $v_o = \sqrt{g_h\,(R+h)}$

Formula shows that orbital speed of a satellite depend upon *g*, *R* and *h*.

The orbital velocity of the satellite depends on its altitude above Earth. The nearer Earth, the faster the required orbital velocity.

5.17 Why communication satellites are stationed at geostationary orbits?

Ans: Communications satellites and weather satellites are often given geostationary orbits, so that the satellite antennas that communicate with them do not have to move to track them, but can be pointed permanently at the position in the sky where they stay. A geostationary orbit is a particular type of geosynchronous orbit.

PROBLEMS

5.1 Find the gravitational force of attraction between two spheres each of mass 1000 kg. The distance between the centres of the spheres is 0.5 m. (2.67×10^{-4} N)

Solution: Mass = $m_1 = m_2 = 1000$ kg
Distance between the centres = d = 0.5 m
Gravitational constant = G = 6.673×10^{-11} Nm^2kg^{-2}
Gravitational force = F = ?

$$F = G\frac{m_1 m_2}{d^2}$$

$$F = 6.673 \times 10^{-11} \times \frac{1000 \times 1000}{(0.5)^2}$$

$$= 6.673 \times 10^{-11} \times \frac{(10)^6}{0.25} = \frac{6.673 \times 10^{-11} \times 10^6}{0.25} = \frac{6.673 \times 10^{-5}}{0.25}$$

$$= 26.692 \times 10^{-5} = 2.67 \times 10^{-4}\ N$$

5.2 The gravitational force between two identical lead spheres kept at 1 m apart is 0.006673 N. Find their masses. (10,000 kg each)

Solution: Gravitational force = F = 0.006673 N
Gravitational constant = G = 6.673×10^{-11} Nm^2kg^{-2}
Distance between the masses = d = 1m
Masses = $m_1 = m_2$ = ?

$$F = G\frac{m_1 m_2}{d^2}$$

or $$F = G\frac{m \times m}{d^2} \quad (\text{Let } m_1 = m_2 = m)$$

or $$F = G\frac{m^2}{d^2}$$

or $$m^2 = \frac{F \times d^2}{G}$$

$$m^2 = \frac{0.00673 \times (1)^2}{6.673 \times 10^{-11}} = \frac{\frac{6673}{1000000}}{6.673 \times 10^{-11}} = \frac{6.673 \times 10^{-3}}{6.673 \times 10^{-11}}$$

$$m^2 = 10^8 \Rightarrow \sqrt{m^2} = \sqrt{10^8}$$

$$m = 10^4 = 10000 \text{ kg each}$$

Therefore, mass of each lead sphere is 10000kg.

5.3 Find the acceleration due to gravity on the surface of the Mars. The mass of Mars is 6.42×10^{23} kg and its radius is 3370 km. ($3.77\ ms^{-2}$)

Solution: Mass of Mars = $M_m = 6.42 \times 10^{23}$ kg
Radius of Mars = R_m = 3370 km = 3370 × 1000 m = 3.37×10^6 m
Acceleration due to gravity on the surface of Mars = g_m = ?

or $$g_m = G\frac{M_m}{R^2{}_m}$$

$$g_m = 6.673 \times 10^{-11} \times \frac{6.42 \times 10^{23}}{(3.37 \times 10^6)^2}$$

$$= \frac{6.673 \times 10^{-11} \times 6.43 \times 10^{23}}{11.357}$$

$$= \frac{42.84}{11.357} = 3.77\ ms^{-2}$$

5.4 The acceleration due to gravity on the surface of moon is 1.62 ms^{-2}. The radius of Moon is 1740 km. Find the mass of moon.
(7.35×10^{22} kg)

Solution: Acceleration due to gravity = g_m = 1.62 ms^{-2}
Radius of moon = R_m = 1740 km = 1740 × 1000 m = 1.74×10^6 m
Mass of moon = M_m = ?

$$g_m = \frac{GM_m}{R^2{}_m}$$

or
$$M_m = \frac{g_m \times R^2{}_m}{G}$$

$$M_m = \frac{1.62 \times (1.74 \times 10^5)^2}{6.673 \times 10^{-11}} = \frac{1.62 \times 3 \times 10^{12}}{6.673 \times 10^{-11}} = \frac{4.86 \times 10^{12} \times 10^{11}}{6.673}$$

$M_m = 7.35 \times 10^{22}$ kg

5.5 Calculate the value of *g* at a height of 3600 km above the surface of the Earth. **(4.0 ms^{-2})**

Solution: Height = h = 3600 km = 3600 × 1000 m = 3.6×10^6 m
Mass of Earth = M_e = 6.0×10^{24} kg
Gravitational acceleration g_h = ?

$$g_h = \frac{GM_e}{(R_e+h)^2}$$

$$g_h = 6.673 \times 10^{-11} \times \frac{6.0 \times 10^{24}}{(6.4 \times 10^6 + 3.6 \times 10^6)^2}$$

$$= 6.673 \times 10^{-11} \times \frac{6.0 \times 10^{24}}{(10.0 \times 10^6)^2} = 6.673 \times 10^{-11} \times \frac{6.0 \times 10^{24}}{100 \times 10^{12}}$$

$$= 6.673 \times 10^{-11} \times 6.0 \times 10^{10} = 40 \times 10^{-1} = 4.0 \text{ ms}^{-2}$$

5.6 Find the value of g due to the Earth at geostationary satellite. The radius of the geostationary orbit is 48700 km. **(0.17 ms^{-2})**

Solution: Radius = R = 48700 × 1000 m = 4.87×10^7 m
Acceleration due to gravity = g = ?

$$g = \frac{GM_e}{R^2}$$

$$g = 6.673 \times 10^{-11} \times \frac{6.0 \times 10^{24}}{(4.87 \times 10^7)^2} = 6.673 \times 10^{-11} \times \frac{6.0 \times 10^{24}}{23.717 \times 10^{14}}$$

$$= \frac{6.673 \times 6.0 \times 10^{-1}}{23.717} = \frac{4.0038}{23.717} = 0.17 \text{ms}^{-2}$$

5.7 The value of g is 4.0 ms^{-2} at a distance of 10000 km from the centre of the Earth. Find the mass of the Earth. **(5.99×10^{24} kg)**

Solution: Gravitational acceleration = g = 4.0ms^{-2}
Radius of Earth = R_e = 10000km = 10000 × 1000 m = 10^7 m
Mass of Earth = M_e = ?

$$M_e = \frac{gR^2}{G}$$

$$M_e = \frac{4.0 \times (10^7)^2}{6.673 \times 10^{-11}} = \frac{4.0 \times 10^{14}}{6.673 \times 10^{-11}} = \frac{4.0 \times 10^{14}}{6.673 \times 10^{-11}}$$

$$= 0.599 \times 10^{25} = 5.99 \times 10^{24} \text{ kg}$$

5.8 At what altitude the value of *g* would become one fourth than on the surface of the Earth? **(one Earth's radius)**

Solution: Mass of Earth = M_e = 6.0×10^{24} kg
Radius of Earth = R_e = 6.4×10^6 m

Acceleration due to gravity $g_h = \frac{1}{4} g = \frac{1}{4} \times 10\ ms^{-2} = 2.5\ ms^{-2}$

Altitude above Earth's surface = h = ?

$$g_h = \frac{GM_e}{(R+h)^2}$$

or $$(R + h)^2 = \frac{GM_e}{g_h}$$

Taking square root on both sides

or $$\sqrt{(R+h)^2} = \sqrt{\frac{GM_e}{g_h}}$$

or $$R + h = \sqrt{G\frac{M_e}{g_h}}$$

or $$h = \sqrt{G\frac{M_e}{g_h}} - R$$

or $$h = \sqrt{\frac{6.673 \times 10^{-11} \times 6.0 \times 10^{24}}{2.5}} - 6.4 \times 10^6$$

$$= \sqrt{\frac{40.038 \times 10^{13}}{2.5}} - 6.4 \times 10^6 = \sqrt{16 \times 10^{13} m^2} - 6.4 \times 10^6$$

$$= \sqrt{0.16 \times 10^{12}} - 6.4 \times 10^6 = 0.4 \times 10^6 - 6.4 \times 10^6$$

$$= -6.0 \times 10^6\ m$$

As height is always taken as positive, therefore

$h = 6.0 \times 10^6$ m = One Earth's radius

5.9 A polar satellite is launched at 850 km above Earth. Find its orbital speed. ($7431\ ms^{-1}$)

Solution: Height = h = 850 km = 850 × 1000 m = 0.85×10^6 m

Orbital velocity = v_o = ?

$$v_o = \sqrt{\frac{GM_e}{R+h}}$$

$$v_o = \sqrt{\frac{6.673 \times 10^{-11} \times 6 \times 10^{24}}{6.4 \times 10^6 + 0.85 \times 10^6}} = \sqrt{\frac{40.038 \times 10^{13}}{7.25 \times 10^6}}$$

$$= \sqrt{5.55 \times 10^7} = \sqrt{55.5 \times 10^6}$$

$$= 7.431 \times 10^3 = 7431\ ms^{-1}$$

5.10 A communication satellite is launched at 42000 km above Earth. Find its orbital speed. ($2876\ ms^{-1}$)

Solution: Height = h = 42000km = 42000 × 1000m = 42×10^6 m

Orbital velocity = v_o = ?

$$v_o = \sqrt{\frac{GM_e}{R+h}}$$

$$v_o = \sqrt{\frac{6.673 \times 10^{-11} \times 6 \times 10^{24}}{6.4 \times 10^6 + 42 \times 10^6}}$$

$$= \sqrt{\frac{40.038 \times 10^{13}}{48.4 \times 10^6}}$$

$$= \sqrt{\frac{400.38 \times 10^{12}}{48.4 \times 10^6}} = \sqrt{8.27 \times 10^6}$$

$$= 2.876 \times 10^3 = 2876\ ms^{-1}$$